Quantum Universe

The Revolution in 21st-Century Particle Physics

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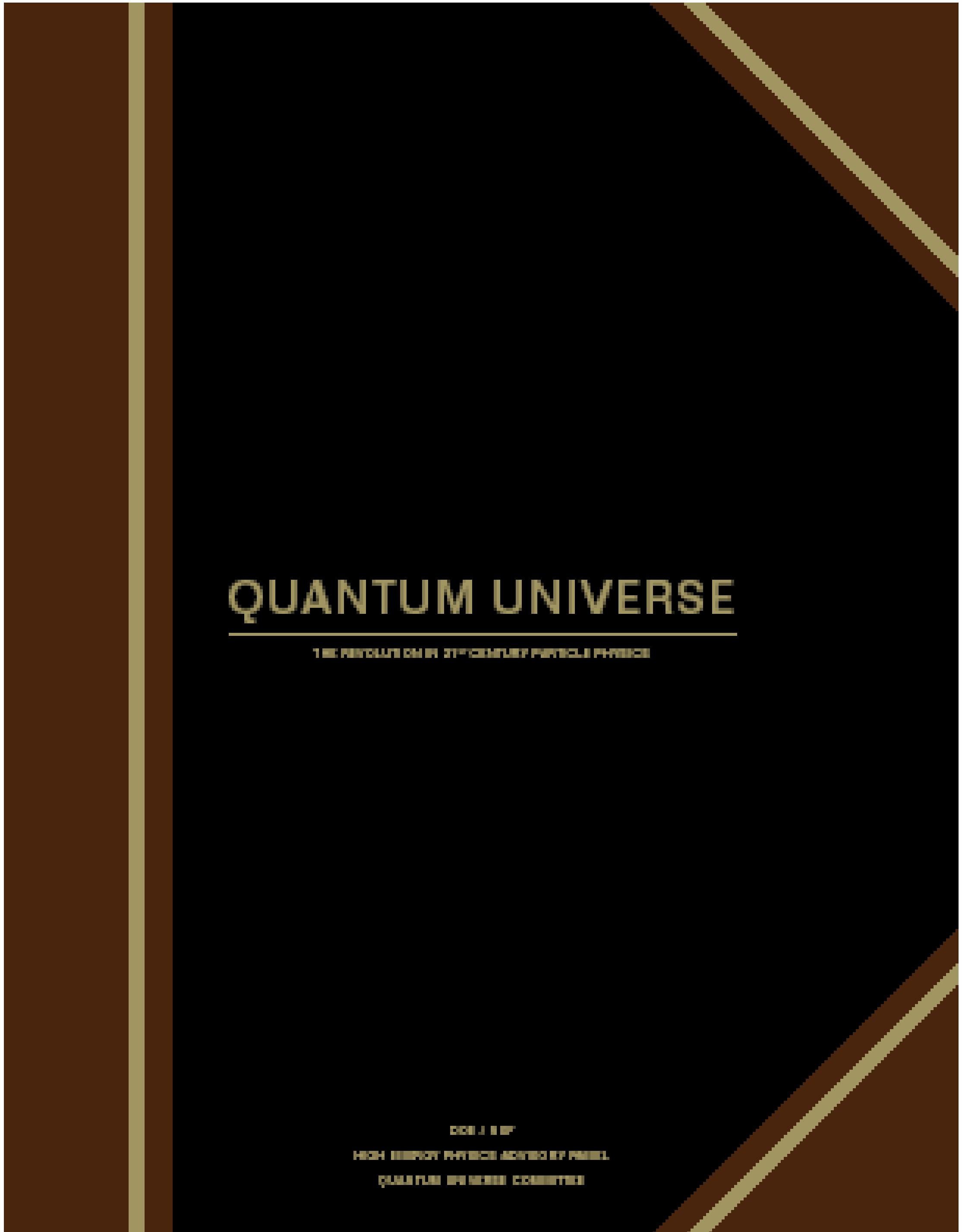
SLAC


QUANTUM UNIVERSE

The Charge

- "Recent scientific discoveries at the energy frontier and in the far reaches of the universe have redefined the scientific landscape for cosmology, astrophysics and high energy physics, and revealed new and compelling mysteries."

- "We are writing to ask the High Energy Physics Advisory Panel (HEPAP) to take the lead in producing a report which will illuminate the issues, and provide the funding and science policy agencies with a clear picture of the connected, complementary experimental approaches to the truly exciting scientific questions of this century."

- This report is the opportunity to describe why this is the most exciting time in particle physics in over a half a century, if not much longer.

Membership of the Committee

- Andreas Albrecht
  UC Davis
- Sam Aronson BNL
- Jon Bagger JHU
- Keith Baker Hampton
- Neil Calder SLAC
- Persis Drell SLAC
- Evalyn Gates
  U of Chicago
- Fred Gilman
  CMU
- Judy Jackson FNAL
- Steve Kahn SLAC
- Rocky Kolb FNAL
- Joe Lykken FNAL
- Hitoshi Murayama
  U C Berkeley
- Hamish Robertson
  U of Washington
- Jim Siegrist
  U C Berkeley
- Simon Swordy
  U of Chicago
- John Womersley FNAL

Schedule

- Weekly telecons since mid-October
- Trip to DC: 11/18
- Face to face at SLAC: 1/20
- Draft of Rougher Text: 2/1
- Draft of Rough Edited Text: 2/15
- Complete Draft: 3/1
- Review by Committee: 3/23
- Final Draft Text to HEPAP: 4/1
- Discussion with HEPAP: 4/19
- Follow through in Washington and with the community after approval of HEPAP

What we heard from our Customers

- Talked to Customers (11/18/03)
  - Holland, Looney, Marburger, Parriott, Turner, Staffin, Dehmer, Orbach
- What we heard:
  - Lead with the science!
  - We see a large array of tools that are seemingly unconnected.
    - “Why can’t we discover the Higgs with ICECUBE?”
  - Articulate the questions that are driving the field
    - give a roadmap: how will we answer these questions, what is the toolkit?
  - Show how scientific questions map onto experimental space
    - How are the different tools connected?
- We have taken this input very seriously

Organization of Report

- Layered document
  - Increasing technical detail
  - Repetition is important
- Executive Summary
  - Stand alone document
  - Articulates the questions that define the field
  - Does not include map of tools onto questions

Organization of Report (cont.)

- Main Document: Five sections

I. **Introduction**

II. **The Fundamental Nature of Matter and Energy, Space and Time**
   - Introduces the nine questions
   - Explains questions in language for non expert (appropriate for Congressional staffer)

III. **Tools for a Scientific Revolution**
   - Repeats questions
   - Articulates questions in more technical detail (appropriate for agency people; assumes significant familiarity with HEP program)
   - Discusses tools to make progress

IV. **Conclusions**

V. **Summary Tables**
   - Requested by Customers

The Questions

Einstein's Dream of Unified Forces

1. Are there undiscovered principles of nature: new symmetries, new physical laws?

The quantum ideas that so successfully describe familiar matter fail when applied to cosmic physics. Solving the problem requires the appearance of new forces and new particles signaling the discovery of new symmetries—undiscovered principles of nature's behavior.

2. How can we solve the mystery of dark energy?

The dark energy that permeates empty space and accelerates the expansion of the universe must have a quantum explanation. Dark energy might be related to the Higgs field, a force that fills space and gives particles mass.

3. Are there extra dimensions of space?

String theory predicts seven undiscovered dimensions of space that give rise to much of the apparent complexity of particle physics. The discovery of extra dimensions would be an epochal event in human history; it would change our understanding of the birth and evolution of the universe. String theory could affect the way the force of gravity behaves.

4. Do all the forces become one?

At the most fundamental level all forces and particles in the universe may be related, and all the forces might be manifestations of a single grand unified force, realizing Einstein's dream.

The Questions (cont.)

The Particle World

5. Why are there so many kinds of particles?

Why do three families of particles exist, and why do their masses differ so dramatically? Patterns and variations in the families of elementary particles suggest undiscovered underlying principles that tie together the quarks and leptons of the Standard Model.

6. What is dark matter? How can we make it in the laboratory?

Most of the matter in the universe is unknown dark matter, probably heavy particles produced in the big bang. While most of these particles annihilated into pure energy, some remained. These remaining particles should have a small enough mass to be produced and studied at accelerators.

7. What are neutrinos telling us?

Of all the known particles, neutrinos are the most mysterious. They played an essential role in the evolution of the universe, and their tiny nonzero mass may signal new physics at very high energies.

The Questions (cont.)

The Birth of the Universe

8. How did the universe come to be?

According to cosmic theory, the universe began with a singular explosion followed by a burst of inflationary expansion. Following inflation, the universe cooled, passing through a series of phase transitions and allowing the formation of stars, galaxies and life on earth. Understanding inflation requires breakthroughs in quantum physics and quantum gravity.

9. What happened to the antimatter?

The big bang almost certainly produced equal amounts of matter and antimatter, yet the universe seems to contain no antimatter. How did the asymmetry arise?

Primary US Physics Program of Major Facilities

	Unification				Particle World			Birth of the Universe	
Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Tevatron	X				X				
LHC	X	X	X					X	
Linear Collider	X	X	X	X		X			
NuMI/MINOS							X		
ν Superbeams							X		X
BaBar	X				X				X
BTeV	X				X				X
JDEM		X				X			
RHIC								X	
Proton Decay				X					

Primary US Physics Program of Smaller Facilities

	Unification				Particle World			Birth of the Universe	
Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Mini-BooNE							X		
MECO	X				X				
Reactor ν Experiments							X		
CLEO-c					X				
K0PI0									X
Neutrinoless Double Beta Decay				X			X		
SDSS						X			
LSST		X				X			
Underground Dark Matter Detectors						X			
WMAP		X				X		X	
CMB Polarization								X	
Lattice Computational Facilities					X			X	
Precision Gravity			X						

Challenges we faced

- The Questions
  - Making the questions inclusive
  - Making the questions exciting and understandable
- Balance
  - Traditional HEP vs. ‘The New Cosmology’
    - Remember the audience!
- Precision vs. Accuracy vs. Clarity
  - Can’t explain everything
  - Remember the audience!
    - Judy and Neil invaluable in guiding us here
- Title
  - ‘Quarks to the Cosmos’ a hard act to follow!
  - ‘Quantum Universe’ is at least memorable

Challenges we faced (cont.)

- Facilities
  a. What is mentioned in text
     - Tried to be inclusive of all major experiments with submitted proposals, in construction, or in operation, with scientific goals germane to the questions we are asking
     - Included proposed experiments on DOE facilities outlook and NSF MRE list with scientific goals germane to the questions we are asking
     - Included both US and International efforts
  b. When to be generic and when to be specific?
     - Judgment call by the committee on a case by case basis
       - e.g. 'Neutrinoless Double Beta Decay' vs. EXO and Majorana
       - e.g. 'ν superbeams' instead of CERN SPL, FNAL/BNL proton driver, JPARC Phase II, etc....
       - e.g. BTeV and LHC-b instead of 'Hadron B-factories'

Challenges we faced (cont.)

c. What is included in table?
   - Focused on facilities with major US participation
   - Only listed experiments whose primary scientific goals are directed at the questions we are asking.
     - Judgment call on the part of the committee to not include all experiments mentioned in text in the table
     - Wanted to avoid a laundry list
     - Remember to listen to the customers!

d. What does bold face mean and how is it used?
   - When an experiment or facility gets a check in the table for a given question it appears in bold in the corresponding text in section III
     - The use of bold face is confusing
     - We have developed an alternative scheme to highlight facilities (e.g. sidebar next to the question)

EINSTEIN'S DREAM OF UNIFIED FORCES

Superstrings and grand unification are currently the most promising ideas for fulfilling Einstein's dream of an ultimate theory. To understand string theory requires experimental tests of its predictions of supersymmetric particles and extra dimensions of space. To understand unification requires experiments sensitive to extremely rare particle decays. To confront the discrepancy between the theory of the large and the theory of the small requires a better understanding of fundamental quantum physics.

1 ARE THERE UNDISCOVERED PRINCIPLES OF NATURE: NEW SYMMETRIES, NEW PHYSICAL LAWS?

EXPERIMENTAL PROGRAM

Tevatron	BaBar
LHC	Linear Collider
BTeV	MECO

2 HOW CAN WE SOLVE THE MYSTERY OF DARK ENERGY?

EXPERIMENTAL PROGRAM

SNAP	LSST
JDEM	LHC
Linear Collider	

Facilities Included

- Tevatron
- LHC
- Linear Collider
- NuMI/MINOS
- ν Superbeams
- BaBar
- BTeV
- JDEM
- RHIC
- Proton Decay

- SNO, SuperK, KamLand, K2K, JPARC, Cern to GS
- BELLE, LHC-b
- RIA, Underground Laboratory
- GLAST, VERITAS, ICE CUBE, AMS, PLANK, SPT, ACT, LIGO

TEXT but *not* TABLE

- Mini-BooNE
- MECO
- Reactor ν Experiments
- CLEO-c
- K0PI0
- Neutrinoless Double Beta Decay
- SDSS
- LSST
- Underground Dark Matter Detectors
- WMAP
- CMB Polarization
- Lattice Computational Facilities
- Precision Gravity

TEXT and TABLE

Challenges we faced (cont.)

- How are check marks in the table assigned?
  - Highlight facilities with greatest impact
  - Orthogonality
  - ALL CHOICES A JUDGEMENT CALL ON THE PART OF THE COMMITTEE
    - Much discussion
    - Unanimous agreement with final decisions
  - Examples of difficult choices
    - Q6: (Dark Matter) LC gets a check, LHC does not
    - Neutrino experiments checked for Q7 (What are ν telling us) but not Q5 (Why so many particles)
    - Q9: (Antimatter) did not include Tevatron

Summary

- Committee worked extremely well together and has produced what we hope will be a useful document
- Will listen and incorporate comments from HEPAP
- Final printed version with pictures and sidebars is in final design stages with production anticipated by May 14
- Next steps are follow through with customers and community

Connecting Quarks with the Cosmos

1. What is Dark Matter? ★
2. What is the Nature of Dark Energy? ★
3. How Did the Universe Begin? ☆
4. Did Einstein Have the Last Word on Gravity?
5. What are the Masses of the Neutrinos and How Have They Shaped the Evolution of the Universe ☆
6. How Do Cosmic Accelerators Work and What are They Accelerating?
7. Are Protons Unstable?
8. What are the New States of Matter at Exceedingly High Density and Temperature?
9. Are There Additional Space-Time Dimensions? ★
10. How Were the Elements from Iron to Uranium Made?
11. Is a New Theory of Matter and Light Needed at the Highest Energies? ☆